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Analysis of ZH recoil mass

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The precise measurement of the Higgs mass is the most important program at International Linear Collider (ILC). Using $e^+e^- \to ZH$ process, the mass of Higgs boson can be measured by two lepton tracks from decay of Z boson, even if the Higgs boson decays into invisible particles. We report the measurement accuracy on the Higgs recoil mass and the cross sections for $ZH \to \ell^+\ell^- X$ at $\sqrt{s}$=250 GeV with the integrated luminosity of 250 fb^{-1}.

1 Introduction

The Higgs-strahlung $e^+e^- \to ZH$, is the most important mode to study the Higgs mass, branching ratio, etc. at the ILC. Especially, the leptonic decay mode of Z boson realizes the precise measurement of the Higgs mass due to the finite center of mass energy at ILC, for example, the Higgs mass can be measured as the recoil mass against the Z boson (m_{recoil}) by using reconstructed mass and energy of a Z boson as followings;

$$m_{recoil}^2 = s + m_Z^2 - 2 \cdot E_Z \cdot \sqrt{s}, \qquad (1)$$

where $\sqrt{s}$ is the center of mass energy, and m_Z and E_Z are the mass and energy of a Z boson reconstructed by the two lepton tracks. Since the decay products from Higgs bosons are not used in this study, the Higgs mass can be measured even if the Higgs boson decays into invisible particles. In this paper, we report our analysis status on measurement accuracy of the Higgs recoil mass and the cross section of $e^+e^- \to ZH$ by using $ZH \to e^+e^-/\mu^+\mu^- X$.

2 Simulation

In this study, we used the geometry of LDC′ detector model (`LDCPrime_02Sc`), which is prepared for the detector optimization study for ILD. We assumed the mass of Higgs boson as 120 GeV. The center of mass energy was set to 250 GeV, where the initial beam spread was considered to be 0.28% for the electron beam and 0.18% for the positron beam. The beam simulation was done by CAIN [2] with the initial and final state radiation (ISR and FSR) and beamstrahlung. WHIZARD [3] was used as the event generator, and hadronization was done by Pythia 6.409 [4]. The generated events were simulated by Mokka and reconstruction was done by Marlin [5].

We considered only $ZZ \to e^+e^-X/\mu^+\mu^-X$ events as background. The cross section of the signal events were 7.5 fb and these of ZZ events were 78.7 fb for $ZZ \to e^+e^-X$ and 79.0 fb for $ZZ \to \mu^+\mu^-X$. In the analysis, the number of events was scaled to 250 fb^{-1}.

3 Analysis

To identify electrons or muons coming from decay of Z bosons, we reconstructed the invariant mass by using two charged tracks with track energy above 10 GeV. Then, a pair of the

$ZH \to eeX$		
	signal	$ZZ \to eeX$
No cut	1923(1.00)	19685(1.00)
2-track selection	1482(0.771)	11931(0.606)
$85 < M_Z < 97$ GeV	1065(0.554)	7844(0.399)
$\lvert\cos\theta_{lepton}\rvert < 0.95$	967(0.503)	7140(0.363)
$\lvert\cos\theta_Z < 0.9$	891(0.463)	5657(0.287)
$ZH \to \mu\mu X$		
	signal	$ZZ \to \mu\mu X$
No cut	1923(1.00)	19685(1.00)
2-track selection	1766(0.918)	13799(0.701)
$85 < M_Z < 97$ GeV	1530(0.796)	10856(0.552)
$\lvert\cos\theta_{lepton}\rvert < 0.95$	1382(0.718)	9831(0.499)
$\lvert\cos\theta_Z\rvert < 0.9$	1266(0.658)	7659(0.389)

Table 1: Reduction summary. The number of events was scaled to 250 fb^{-1}.

lepton tracks which had the nearest mass to the Z boson was selected. Figure 1 shows the distribution of the reconstructed Z mass. $ZH \to eeX$ events have a wider distribution than the $ZH \to \mu\mu X$ events because electrons emit the bremsstrahlung photons in the tracker. To use well reconstructed events, we applied the selection cut of $85 < M_Z < 97$ GeV for the signal and background events.

We applied the angular cut for the lepton tracks and reconstructed Z bosons. At first, tracks with $|\cos\theta_{lepton}| < 0.95$ was selected since the coverage of TPC is $|\cos\theta| < 0.98$. $e^+e^- \to ZZ$ events are the t-channel process, therefore, the Z boson tends to be generated in forward-backward region. On the other hand, the Z boson is generated uniformly for the signal events because $ee \to ZH$ events come from the s-channel process and the Higgs boson is a scalar particle. We required the angle of the reconstructed Z boson to be $|\cos\theta_Z| < 0.9$.

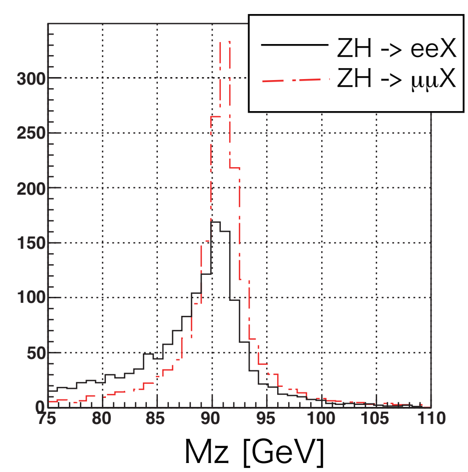

Figure 1: The distribution of the reconstructed Z mass for $ZH \to ee/\mu\mu X$.

Table 1 shows the reduction summary at each selection cut. After all the cuts, the selection efficiency was 46.3% for $ZH \to e^+e^-X$ and 65.8% for $ZH \to \mu\mu X$. On the other hand, the efficiency for the background events was 28.7% and 38.9% for $ZZ \to e^+e^-X$ and $ZZ \to \mu^+\mu^-X$, respectively.

4 Results

Figure 2 shows the distributions of the reconstructed Higgs recoil mass for $ZH \rightarrow e^+e^-/\mu^+\mu^-X$. A peak can be seen around 120 GeV in both distributions. To obtain the Higgs recoil and cross section, the distributions were fitted by the empirical function as follows [6];

$$
\begin{aligned}
F(m) &= N_{sig}e^{-Am}\int F_H(m+t)e^{-\frac{t^2}{2\sigma^2}}dt + F_Z(m), \\
F_H(m) &= \left(\frac{m - M_H}{\sqrt{s} - M_H}\right)^{\beta-1},
\end{aligned}
\tag{2}
$$

where M_H is the mass of Higgs boson, $\sqrt{s}$ is the center of mass energy, and N_{sig} is a normalization factor for the signal events. $F_H(m)$ is a function to take into account of the effect of the bremsstrahlung, which is convoluted with the Gaussian function, and e^{-Am} is a correction term. $F_Z(m)$ is a exponential function to fit the background distribution. The parameters of $F_Z(m)$ except for the normalization factor were determined by using the the independent background samples.

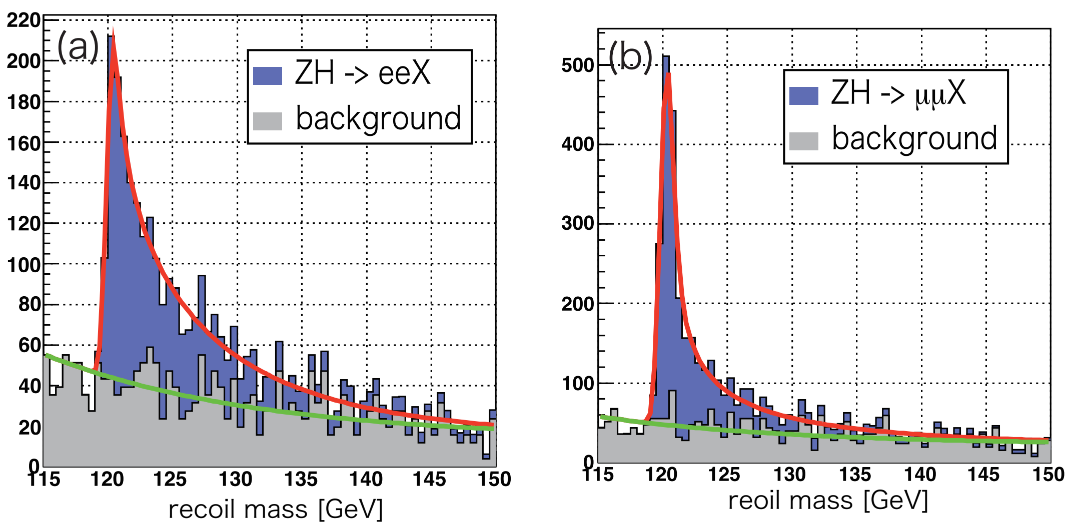

Figure 2: Distribution of the reconstructed Higgs recoil mass for $ZH \rightarrow eeX$ (a) and $ZH \rightarrow \mu\mu X$ (b).

From the fitting results, we obtained the mass of Higgs boson as 120.0 ± 0.10 GeV and 120.1 ± 0.041 GeV for $ZH \rightarrow e^+e^-X$ and $ZH \rightarrow \mu^+\mu^-X$, respectively. The cross section can be calculated from the integral of the fitted function. The measured cross section of $ZH \rightarrow e^+e^-X$ was 7.5 ± 0.35 fb and that of $ZH \rightarrow \mu^+\mu^-X$ was 7.7 ± 0.29 fb, which correspond to measurement accuracy of 4.7% and 3.8%, respectively.

5 Conclusions

$e^+e^- \to ZH$ process is the golden mode to determine the Higgs mass in the ILC, because the Higgs mass can be measured by the recoil mass against the Z boson without any assumptions of the Higgs decay modes. We analyzed the recoil mass at $\sqrt{s}$ =250 GeV with 250 fb^{-1} for the Higgs mass of 120 GeV, where $ee \to ZZ$ is considered as a background. The Higgs boson mass was measured as 120.0 ± 0.10 GeV and 120.1 ± 0.041 GeV for $ZH \to e^+e^-X$ and $ZH \to \mu^+\mu^-X$, respectively. The cross section of $e^+e^- \to ZH \to e^+e^-X$ was 7.5 ± 0.35 fb (4.7%) and that of $e^+e^- \to ZH \to \mu^+\mu^-X$ was 7.7 ± 0.29 fb (3.8%).

Although we included only $ZZ \to \ell^+\ell^-X$ events as background events, other physics processes also become backgrounds. For example, $ee \to e^+e^-/\mu^+\mu^-$ and $WW \to e\nu_e e\nu_e$ contaminate in the signal region. The next step, therefor, is to include these background events.

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